



US Army Corps
of Engineers
Huntington District

One Corps, One Regiment, One Team

Rock Anchor Workshop

Bluestone Lake Dam Safety Assurance Anchor Design

18 September 2002



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Presentation Overview

- Dam Overview
- DSA Overview
- General Geology
- The Need for Anchors

ANCHOR DESIGN

- The Effects of Anchors on Uplift
- Rock Strengths
- Anchor Bond Zone and Depth Design
- Ongoing Studies

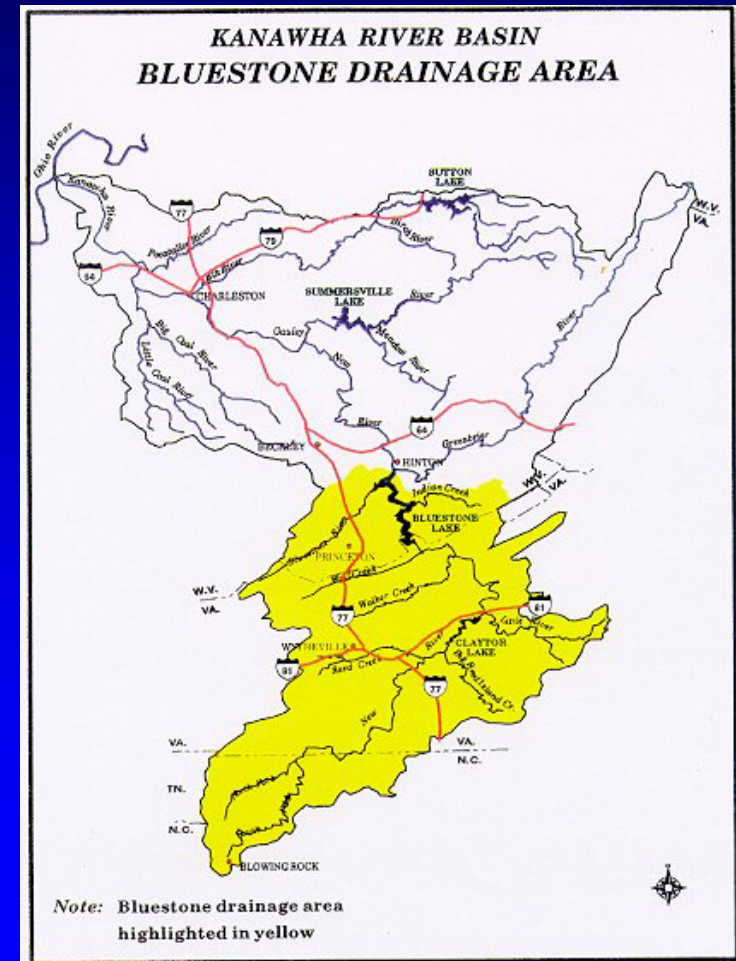




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Location





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Bluestone Dam – Existing Project

- ◆ **Concrete gravity dam**
 - 165' high
 - 2060' long
- ◆ **Outlet works**
 - Sluices
 - Gated spillway
- ◆ **Penstocks**



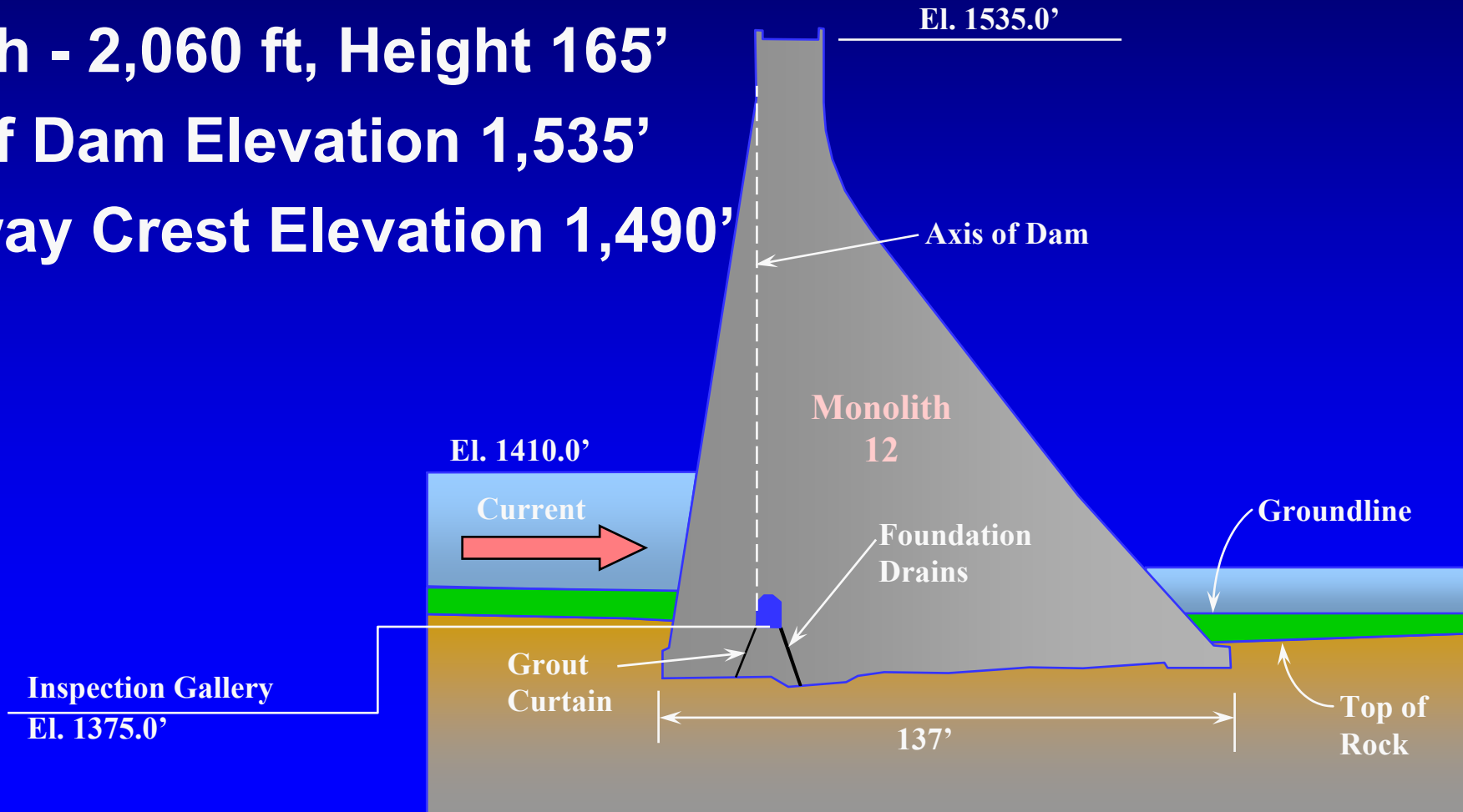


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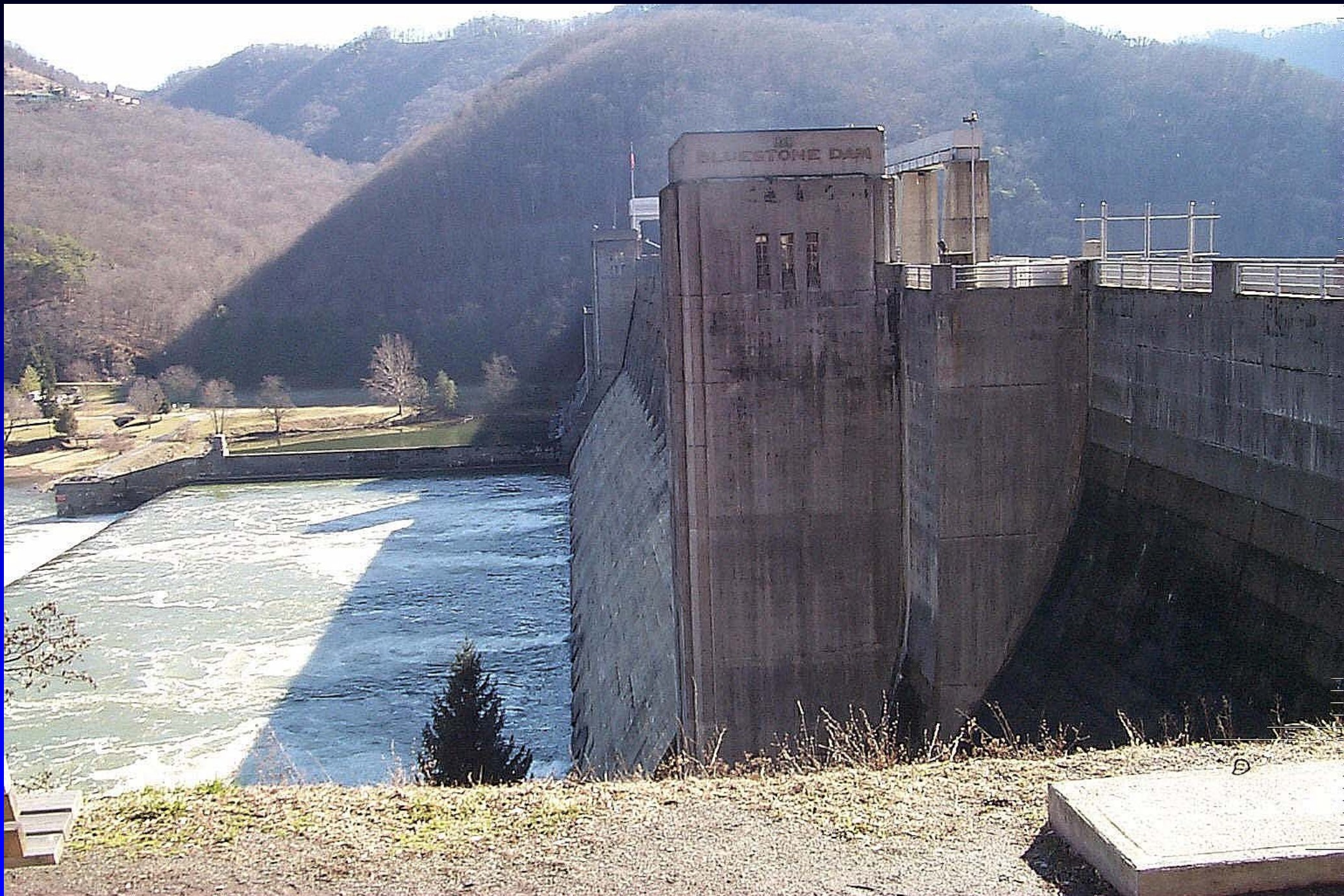
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Bluestone Dam – Existing Project

- ◆ Concrete Gravity Dam - 1940's
- ◆ Length - 2,060 ft, Height 165'
- ◆ Top of Dam Elevation 1,535'
- ◆ Spillway Crest Elevation 1,490'









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Penstocks Area





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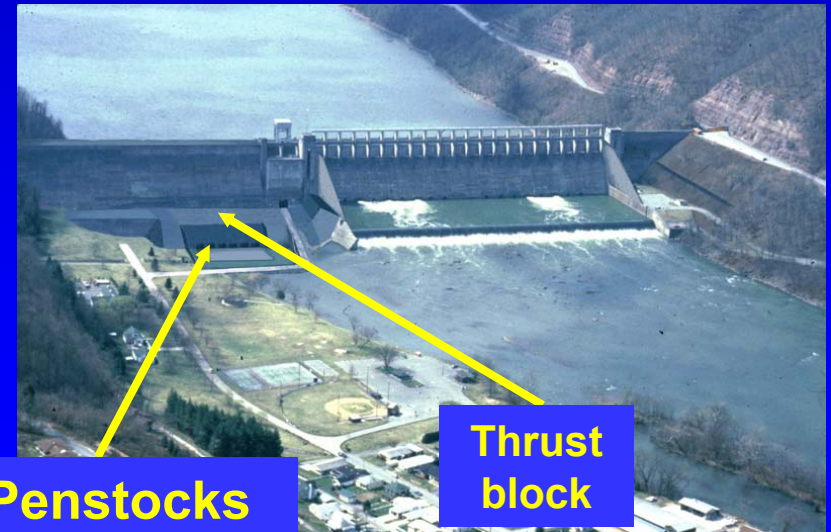
Bluestone DSA Phase I

◆ Project Features

- 2 Lane Bridge
- Thrust Blocks
- Extending Penstocks
- Sacrificial Bulkheads



Bridge



Penstocks

Thrust block



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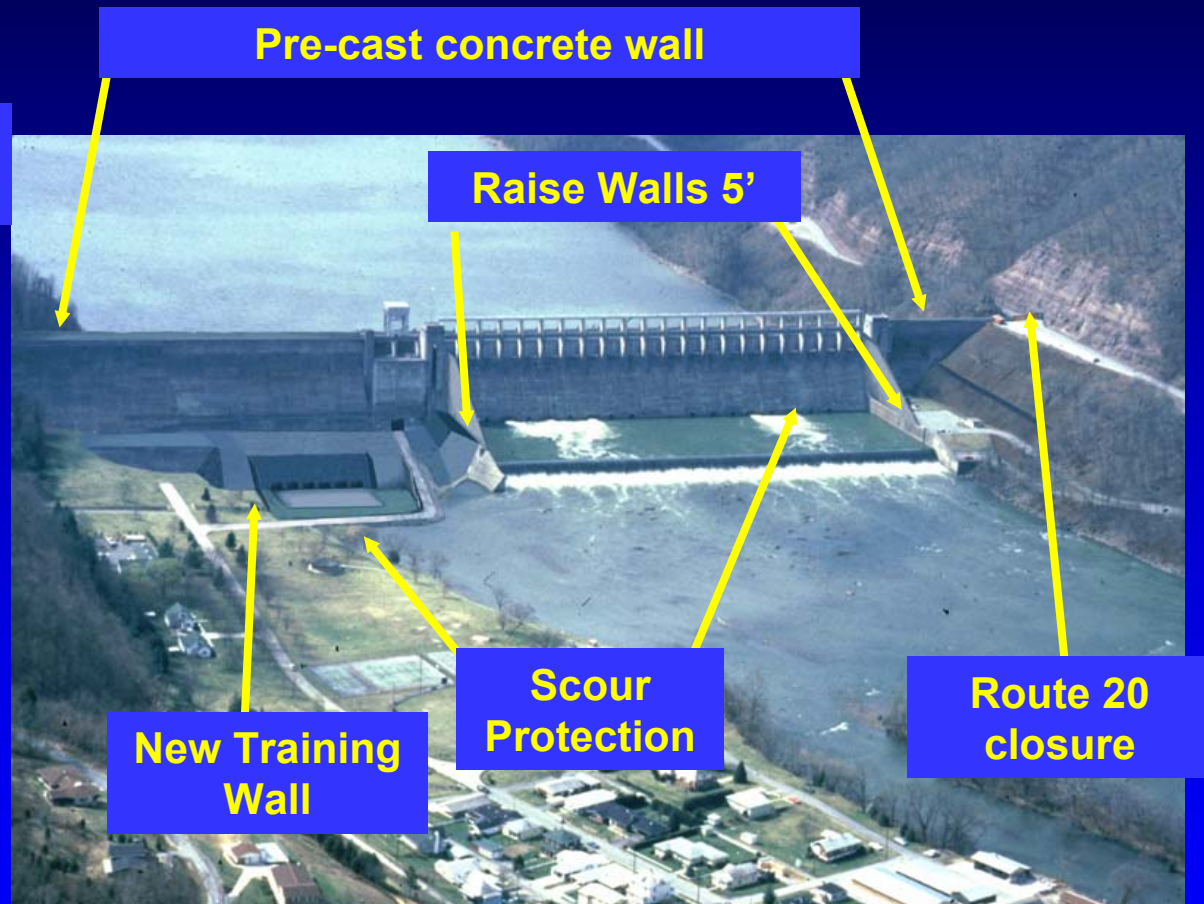
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Bluestone DSA Phase II

New monolith
(not shown)

◆ Project Features

- Anchors (290+)
- Parapet Wall
- Rt 20 Gate Closure
- Scour Protection
- New and modified training walls
- Scour protection



Anchors not shown



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Geology

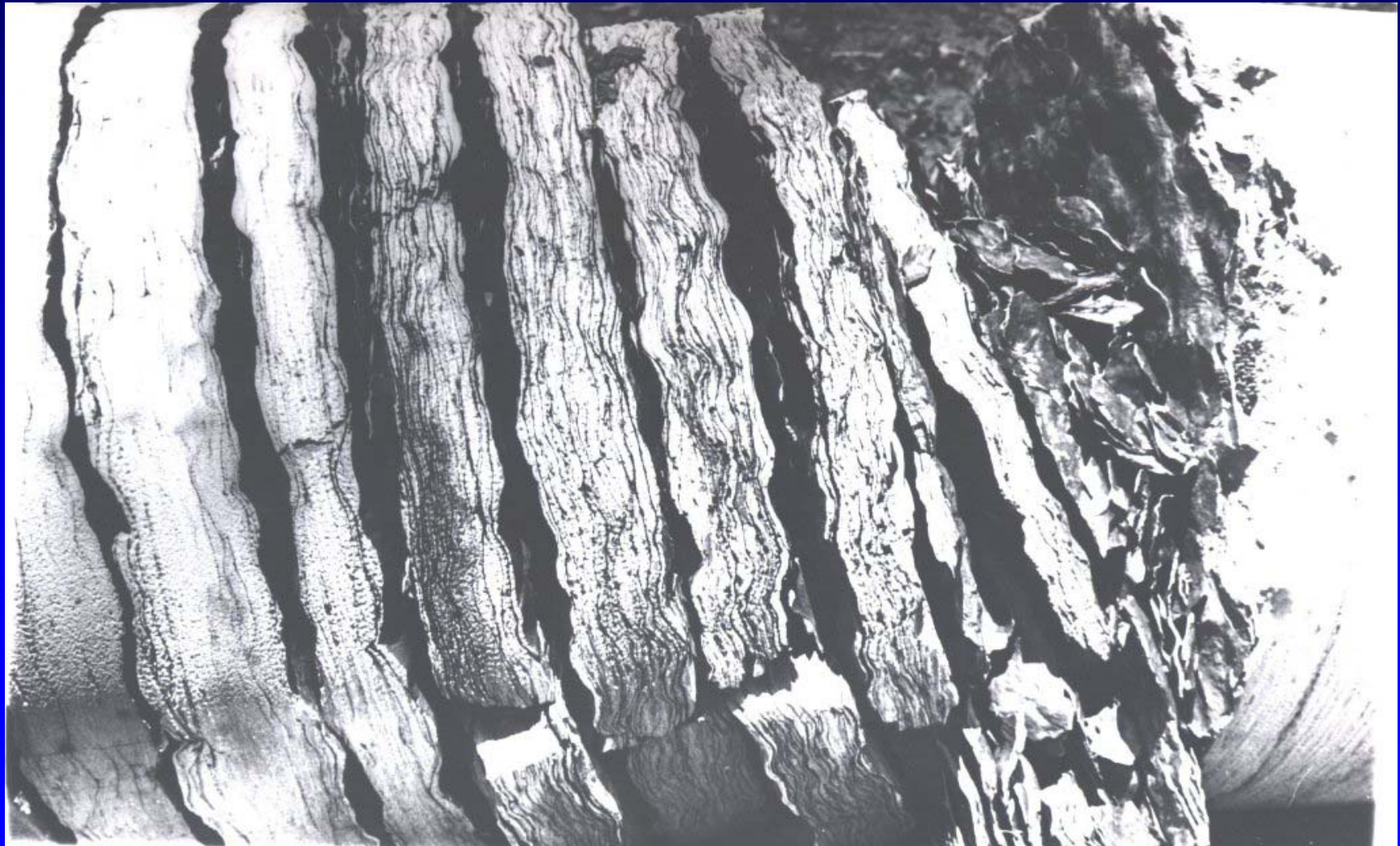
- ◆ **The dam site and vicinity are underlain by Mississippian age rock**
- ◆ **Dam site is in the Hinton Formation**
- ◆ **Mauch Chunk Group**
- ◆ **The abutments are comprised of interstratified shales, siltstones and sandstones**
- ◆ **Dam is founded on the Stoney Gap Sandstone**
- ◆ **Bellepoint Syncline strikes perpendicular to the dam through the right abutment**



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Exploration 1936

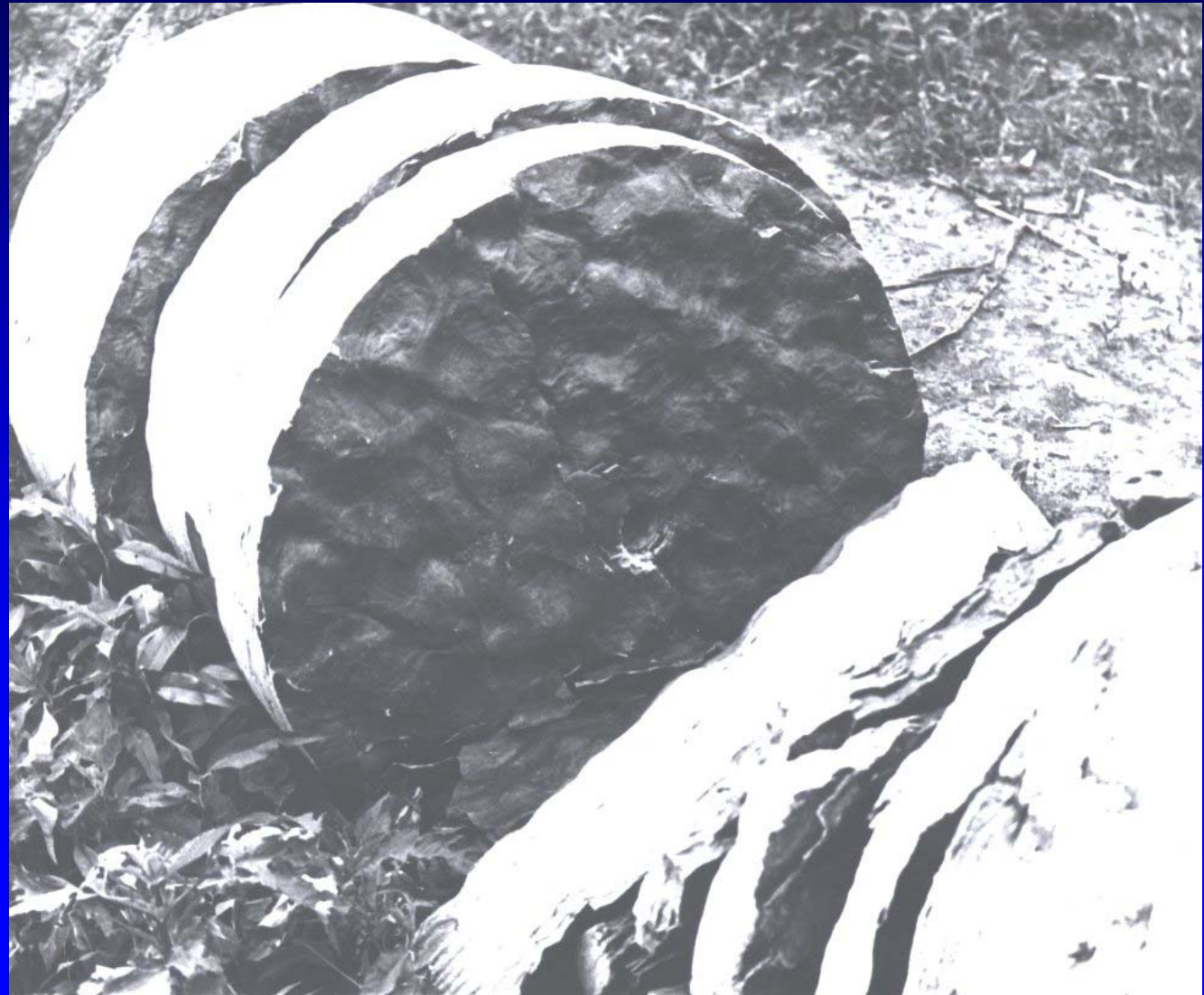




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Exploration 1936





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Construction Photo Mon. 17 - 1943





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Construction Photo Mon. 21 - 1943





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Construction Photo 2001





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Foundation Conditions

◆ Construction Events

- * Consolidation Grouting, 879 borings averaging 45', using 89,666 bags of cement.
- * Various grout curtains, 815 borings, using 73,086 bags of cement
- * Gouge Zones, 18" thick, in Monoliths 11 through 16





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Foundation Conditions





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The Need For Anchors

Comments from the 1969 First Periodic Inspection Report

- ◆ “A study should be made to determine if the powerhouse excavation is detrimental to the safety of the dam.”
- ◆ “A stability check of the concrete sections should be made using current criteria.”



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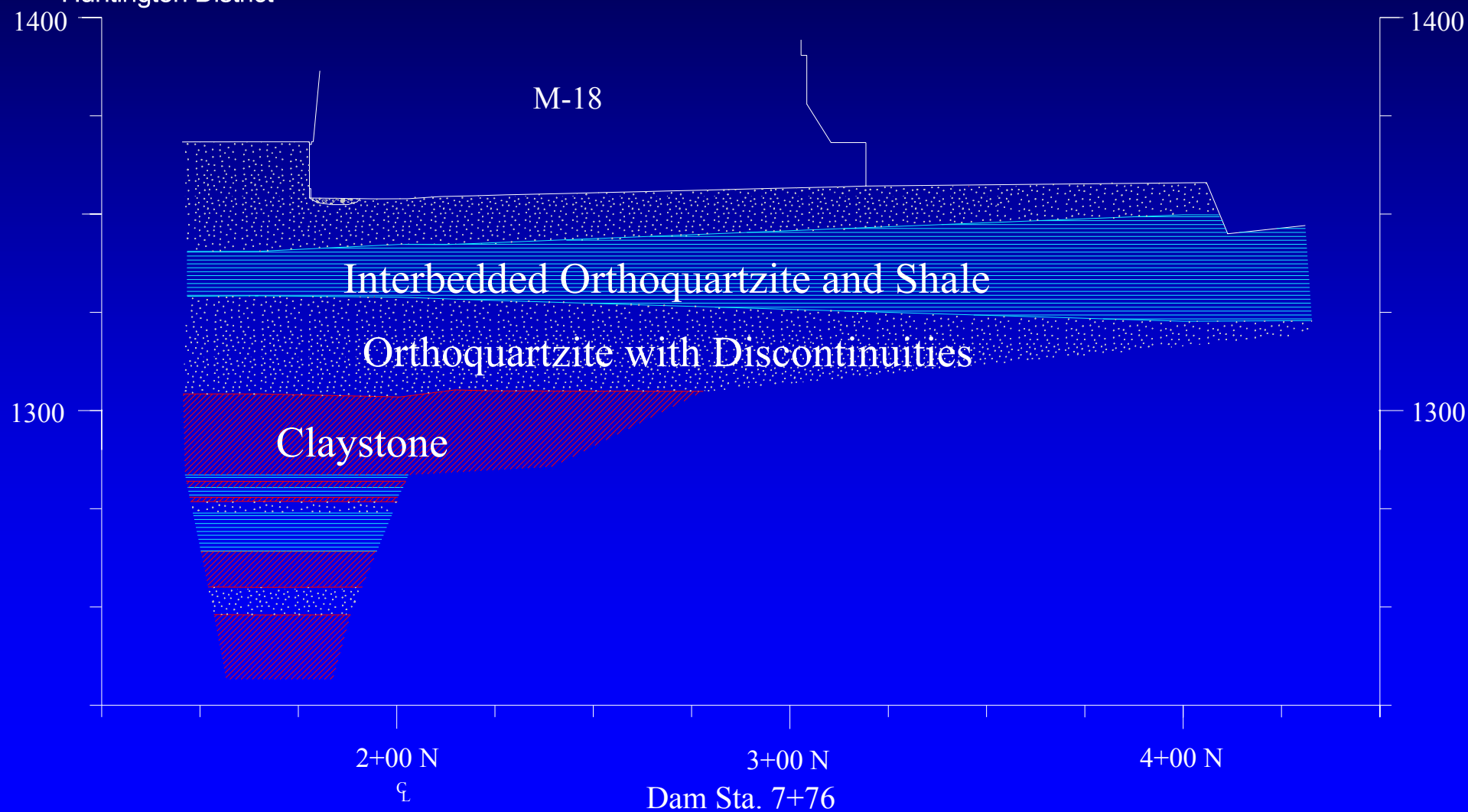
Penstocks Area





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Penstock Monolith





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Anchor Design

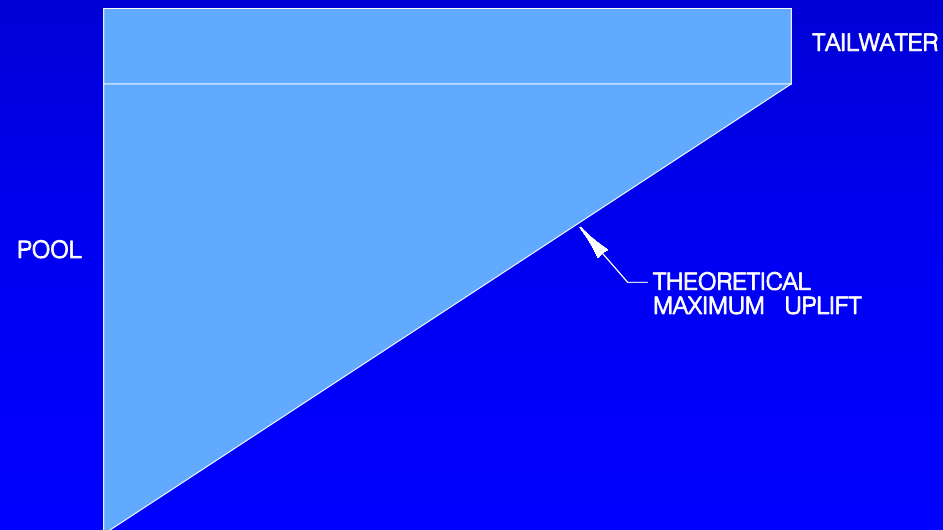
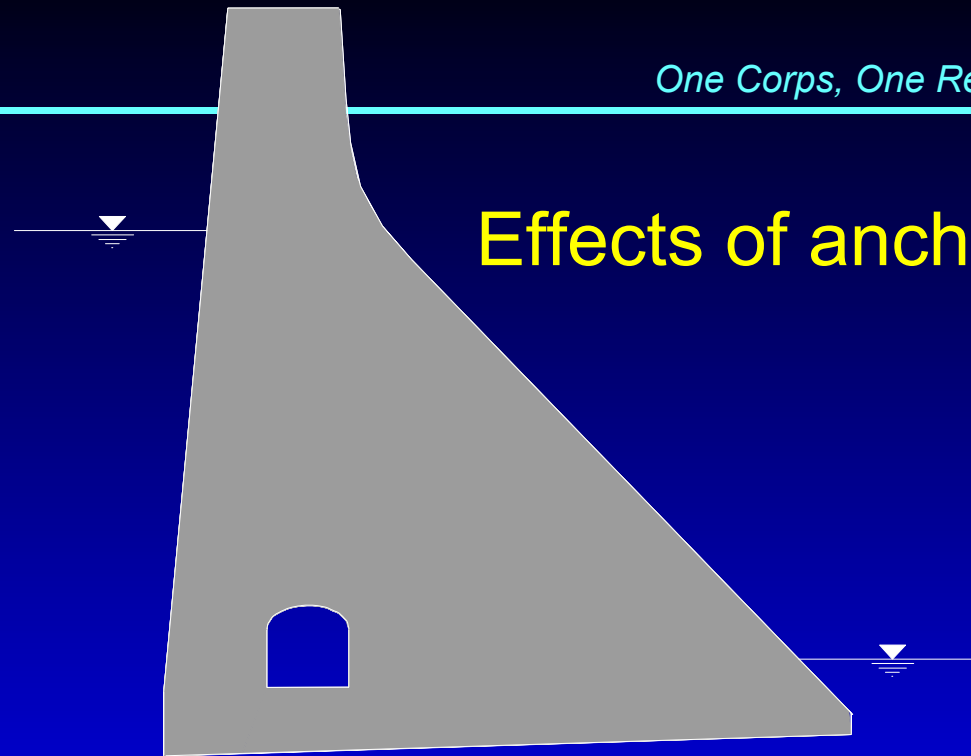
- ◆ The effects of anchors on uplift
- ◆ Rock Strengths
- ◆ Anchor depth
- ◆ Bond zone development
- ◆ Ongoing field study



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Effects of anchors on uplift

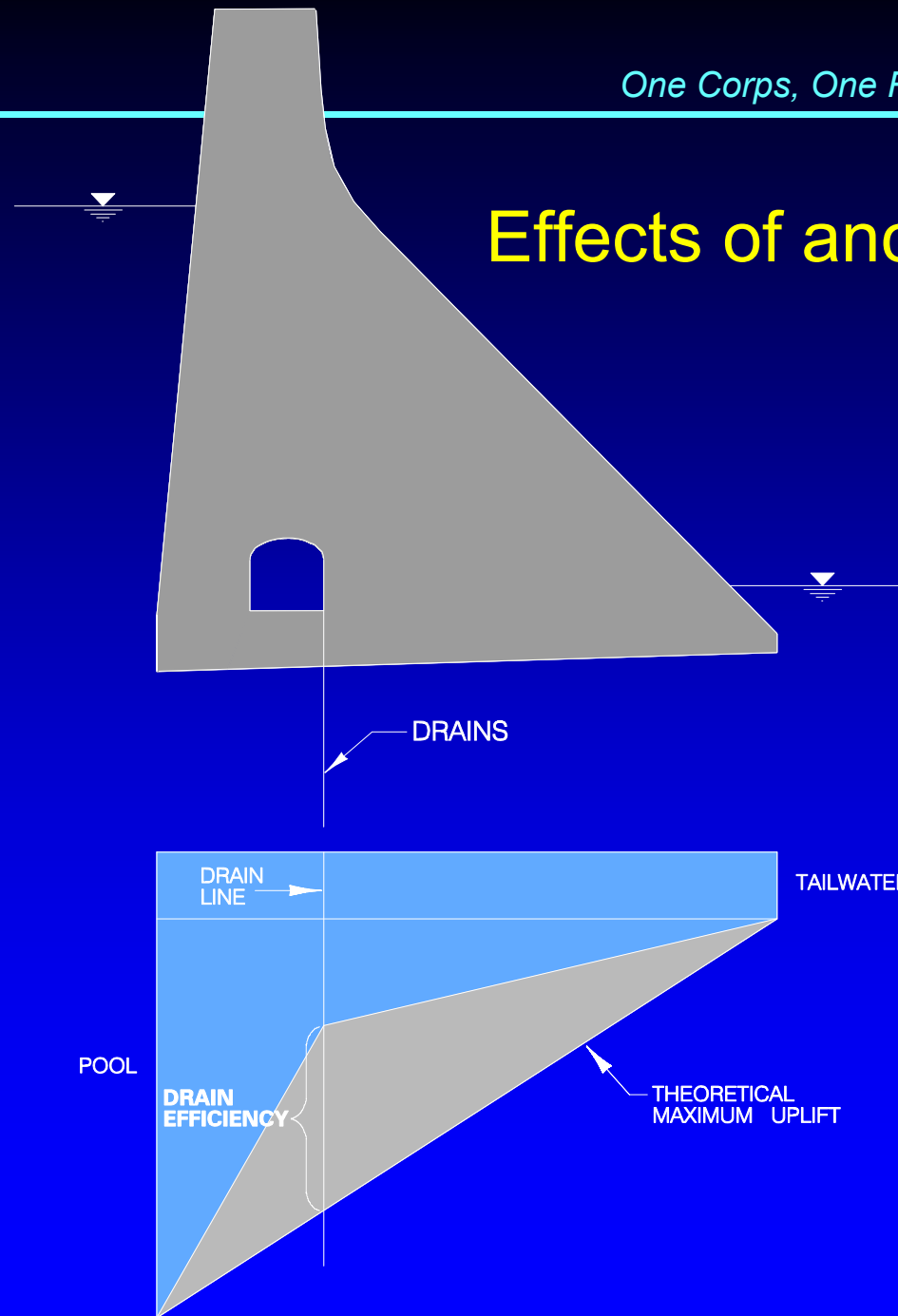




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Effects of anchors on uplift

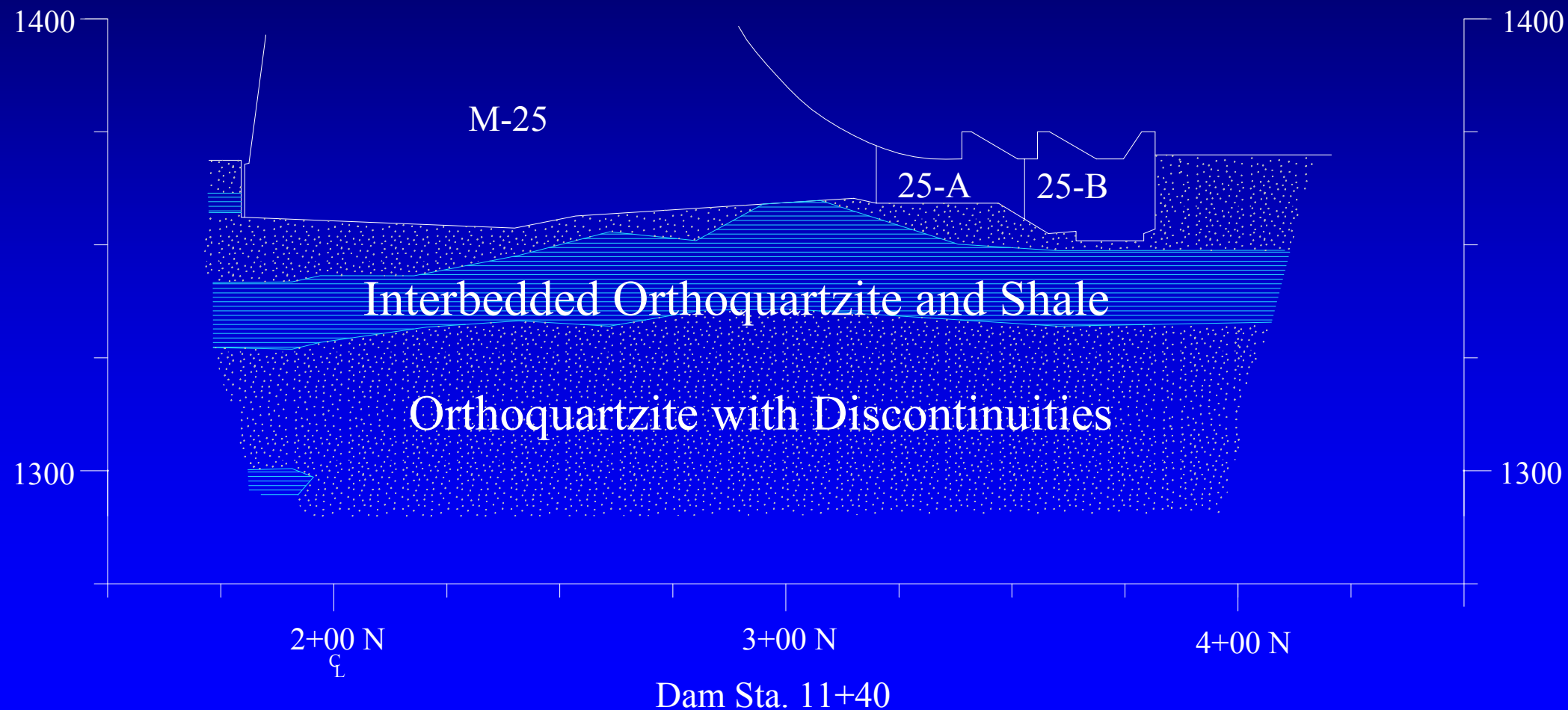




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Effects of anchors on uplift



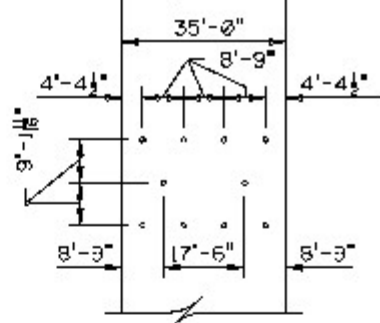


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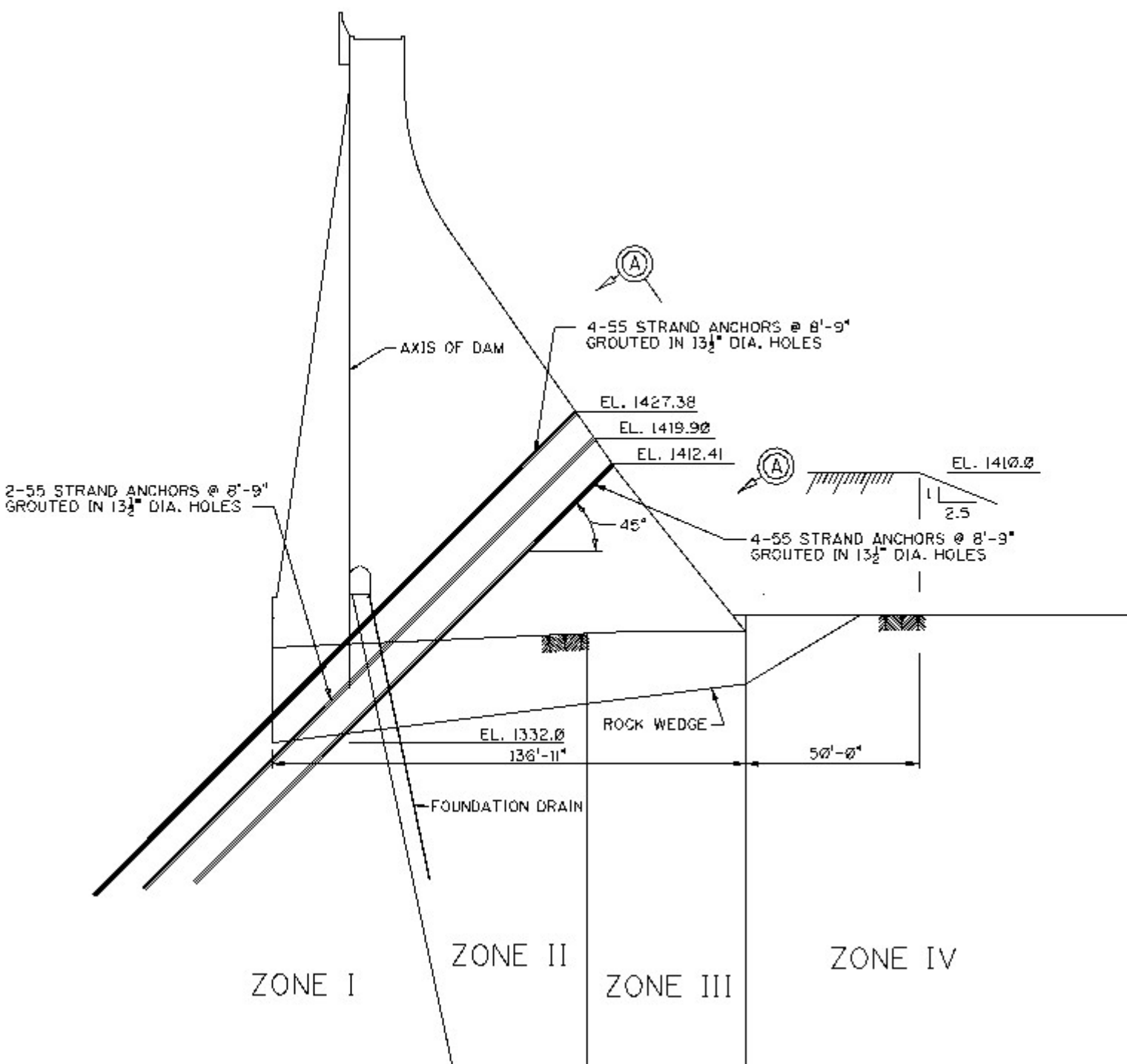
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Drain Efficiency with Proposed Anchor Designs

- 1. Number of anchors per monolith**
- 2. Diameter of borehole**
- 3. Grout penetration**
- 4. Location in the foundation of each anchor**



Section A-A



Reduction Factor of Total Efficiency Due to Installation of Anchors for Monolith 14

Monolith width	35	feet
Anchor hole dia.	1.125	feet
Est. grout penetration	0.66	feet
Reduction factor	$(\text{anchor hole dia} + (\text{grout penetration} \times 2)) / \text{monolith width}$	
Reduction factor per anchor	6.99%	

	Numbers of anchors	Zone Multiplier		
Zone 1	4	0	Reduction factor	0.0%
Zone 2	6	1	Reduction factor	41.9%
Zone 3	0	2	Reduction factor	0.0%
Zone 4	0	3	Reduction factor	0.0%
			TOTAL REDUCTION	42%

Drain efficiency w/o anchors **50%****Drain efficiency with anchors** **29%**

Drain efficiency with anchors = Drain efficiency without anchors reduced by the total reduction percentage

Multiplier to be used with Reduction Factor

ZONE 1 = The area along the base from the Heel to 5ft upstream of the drains.
Multiplier for Zone 1 = 0

ZONE 2 = The area along the base from 5ft upstream of the drains to the end of the second third of the base
Multiplier for Zone 2 = 1

ZONE 3 = The area along the base from the second third of the base to the toe of the dam
Multiplier for Zone 3 = 2

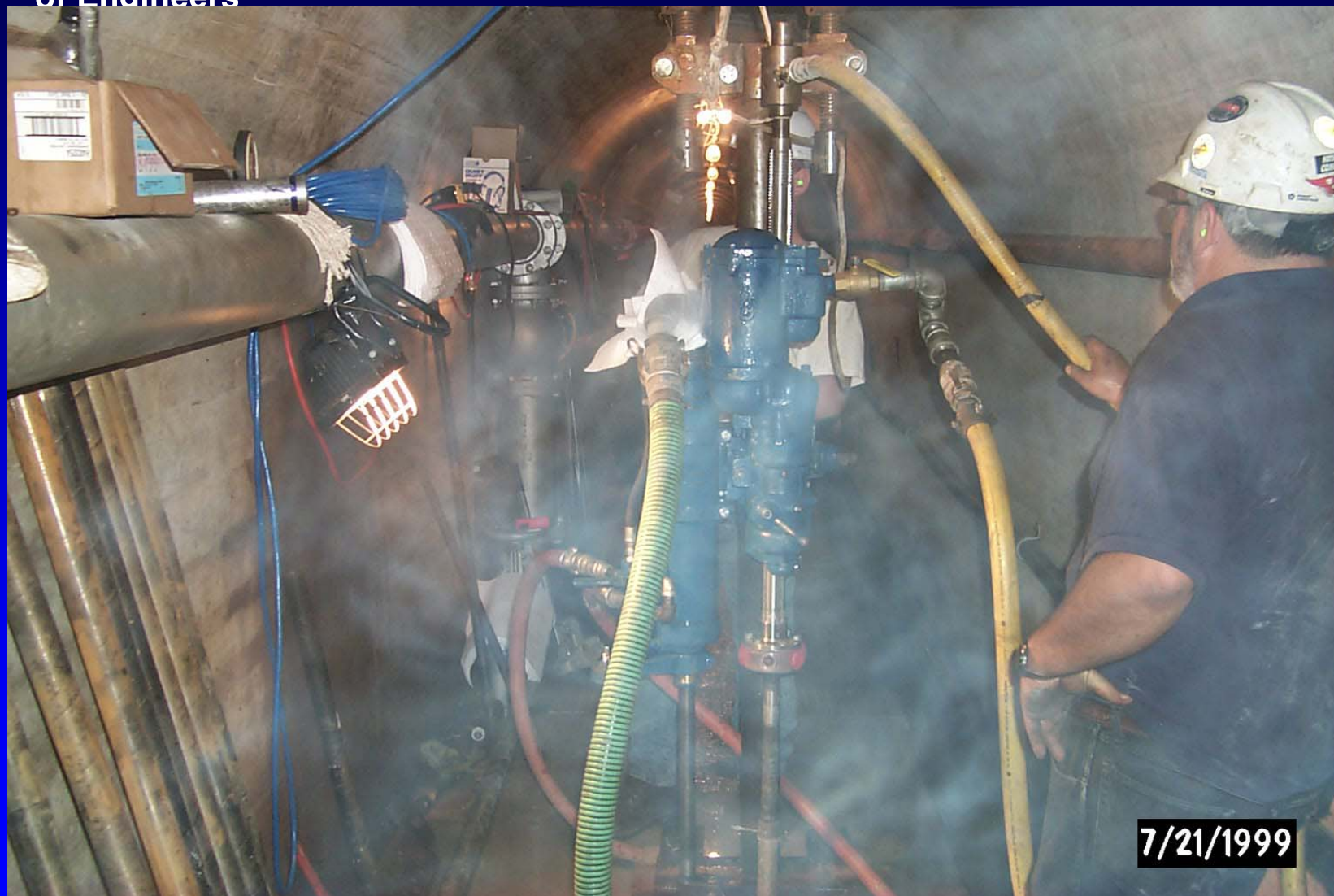
ZONE 4 = Any structures added to the toe such as (stilling basin aprons & thrust blocks)
Multiplier for Zone 4 = 3



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Evaluation of Foundation





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Evaluation of Foundation



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Evaluation of Foundation

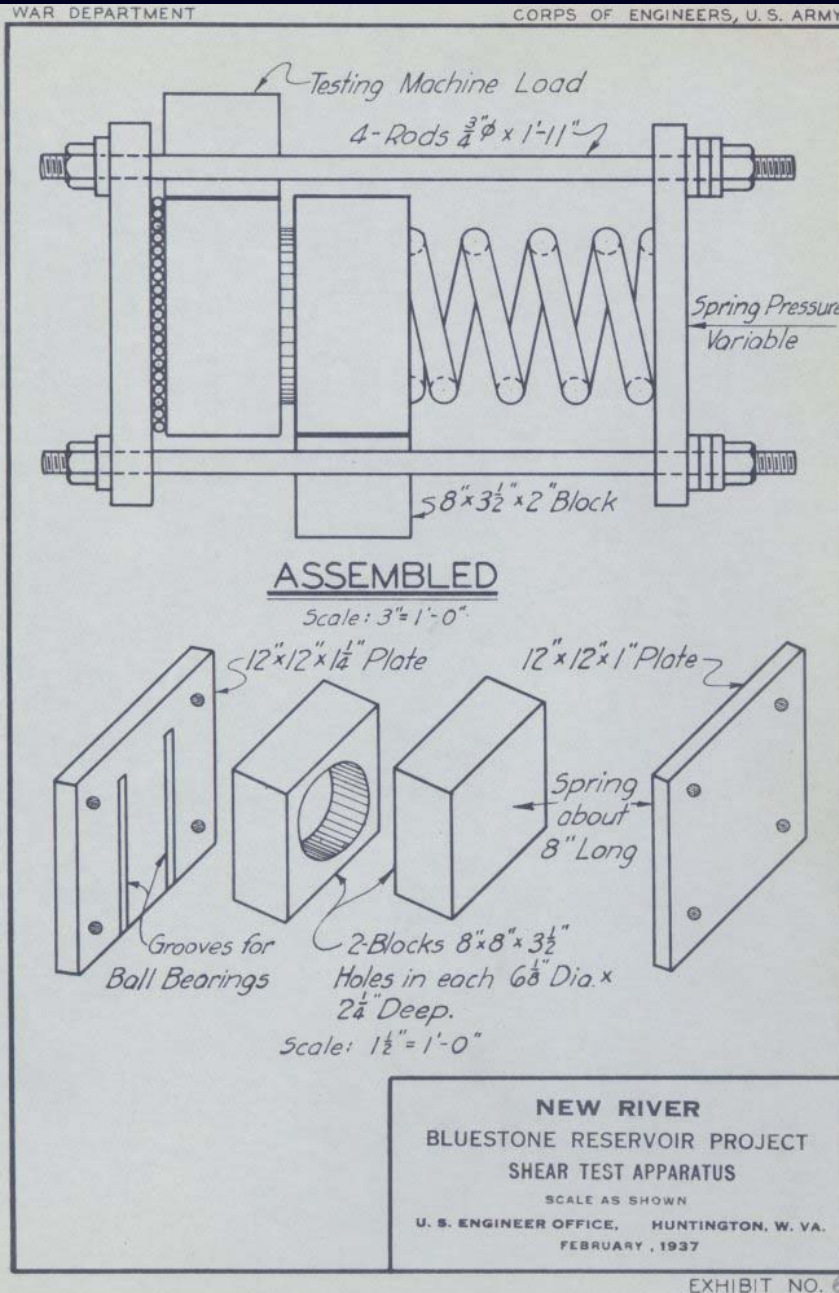
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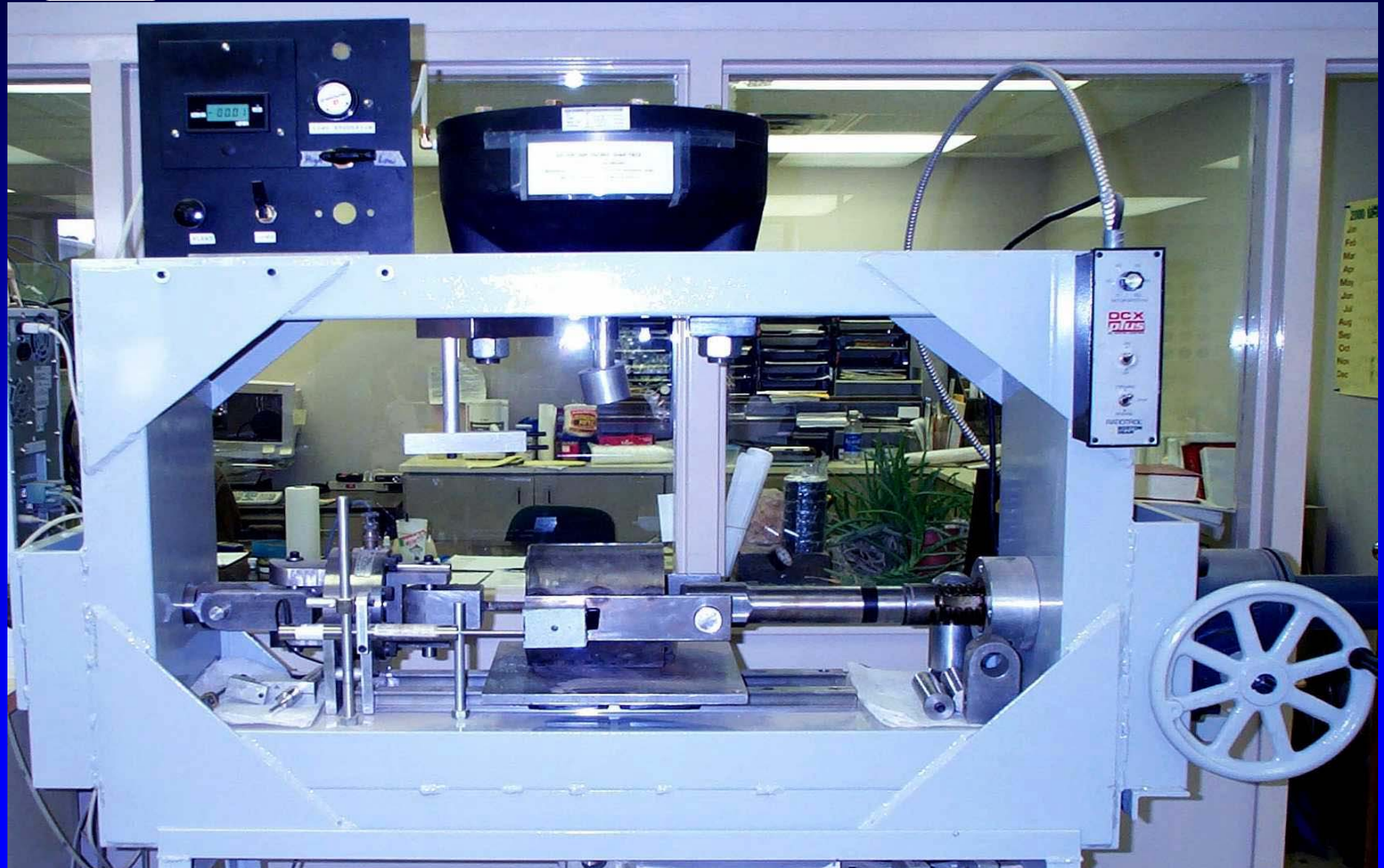


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Early shear test apparatus

Modern USACE Designed Shear Machine

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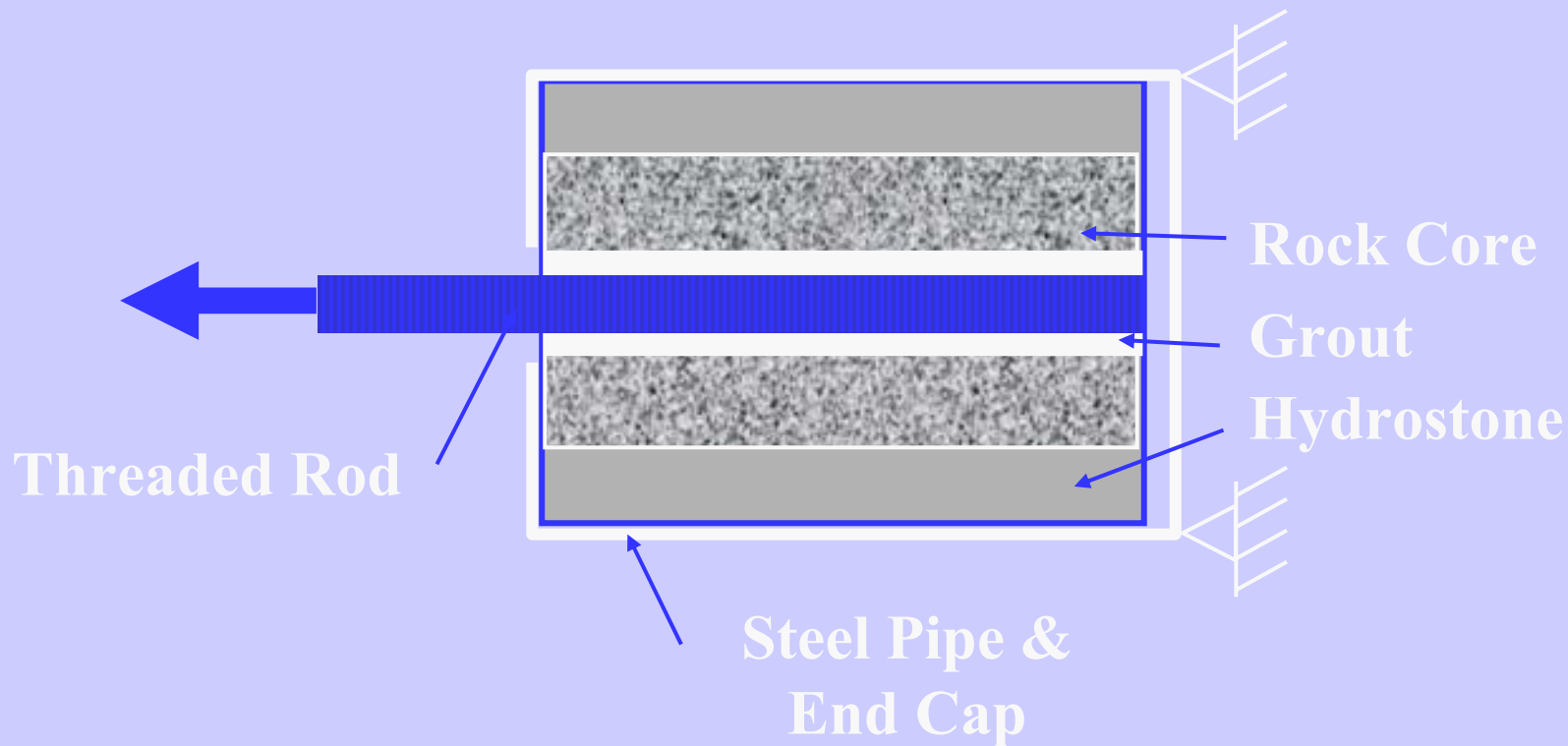




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Bond Stress Schematic





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Original Design Parameters for Rock

Intact Rock Strengths from 1936 Design
(No Natural Fracture Strengths Tested)

- ◆ Sandstone $C = 60 \text{ psi}$ $\Phi = 34$
- ◆ Laminated Rock $C = 60 \text{ psi}$ $\Phi = 35$
- ◆ Shale $C = 60 \text{ psi}$ $\Phi = 0$



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Rock Strength Parameters 2002

	Intact Peak (ϕ) (c)	Natural Fracture (ϕ) (c)	Smooth Sawn Surface (ϕ) (c)	Grout on Rock (ϕ) (c)	Working Bond Strength	Allowable Bearing	Modulus of Deformation ($\times 10^6$)	Average Poisson's Ratio	Unit Weight
Shale	25	19	14	17					
Carbonaceous	6 psi	2 psi	0 psi	16 psi	50 psi	202 psi	1.016	0.34	167 pcf
Siltstone gray	27	22	17	23					
	20 psi	3 psi	0 psi	40 psi	50 psi	301 psi	1.057	0.31	169 pcf
Siltstone maroon	37	29	22	29					
	14 psi	2 psi	0 psi	15 psi	55 psi	355 psi	0.716	0.26	172 pcf
Interbedded SS & SH	25 (1)	19 (1)	14 (1)	17 (1)	(2)	(1)			(1)
	6 psi	2 psi	0 psi	16 psi	130 psi	202 psi	N/A	N/A	167 pcf
Interbedded SS & SLS gray	27 (1)	22 (1)	17 (1)	23 (1)	(2)	(1)			(1)
	20 psi	3 psi	0 psi	40 psi	130 psi	301 psi	N/A	N/A	169 pcf
Sandstone	60	27	26	45					
	70 psi	6 psi	0 psi	135 psi	230 psi	1842 psi	3.613	0.25	172 pcf
Orthoquartzite	65	30	27.5	50					
With Discontinuities	200 psi	11 psi	1.5	40 psi	200 psi	1702 psi	4.032	0.104	160 pcf
Orthoquartzite	46	32	27.5	50					
Interbedded shale	28 psi	6 psi	1.5	40 psi	130 psi	668 psi	1.539	0.165	165 pcf
Claystone	N/A	N/A	N/A	N/A	50 psi	N/A	N/A	N/A	N/A
Broken Zone		13							
	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A



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Anchor Design

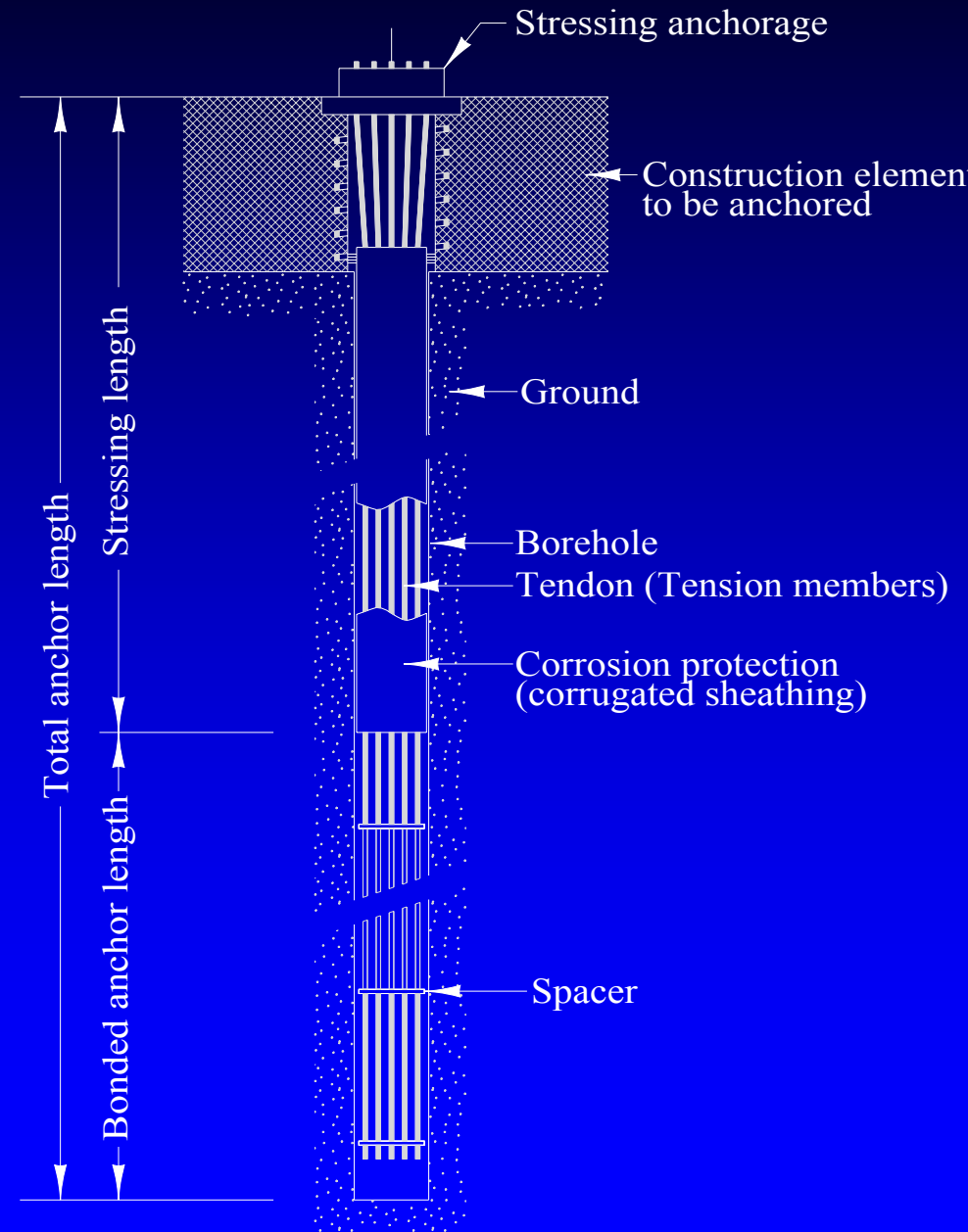
◆ Anchor Depth and Bond Zone Design



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Typical Multi-Strand Anchor

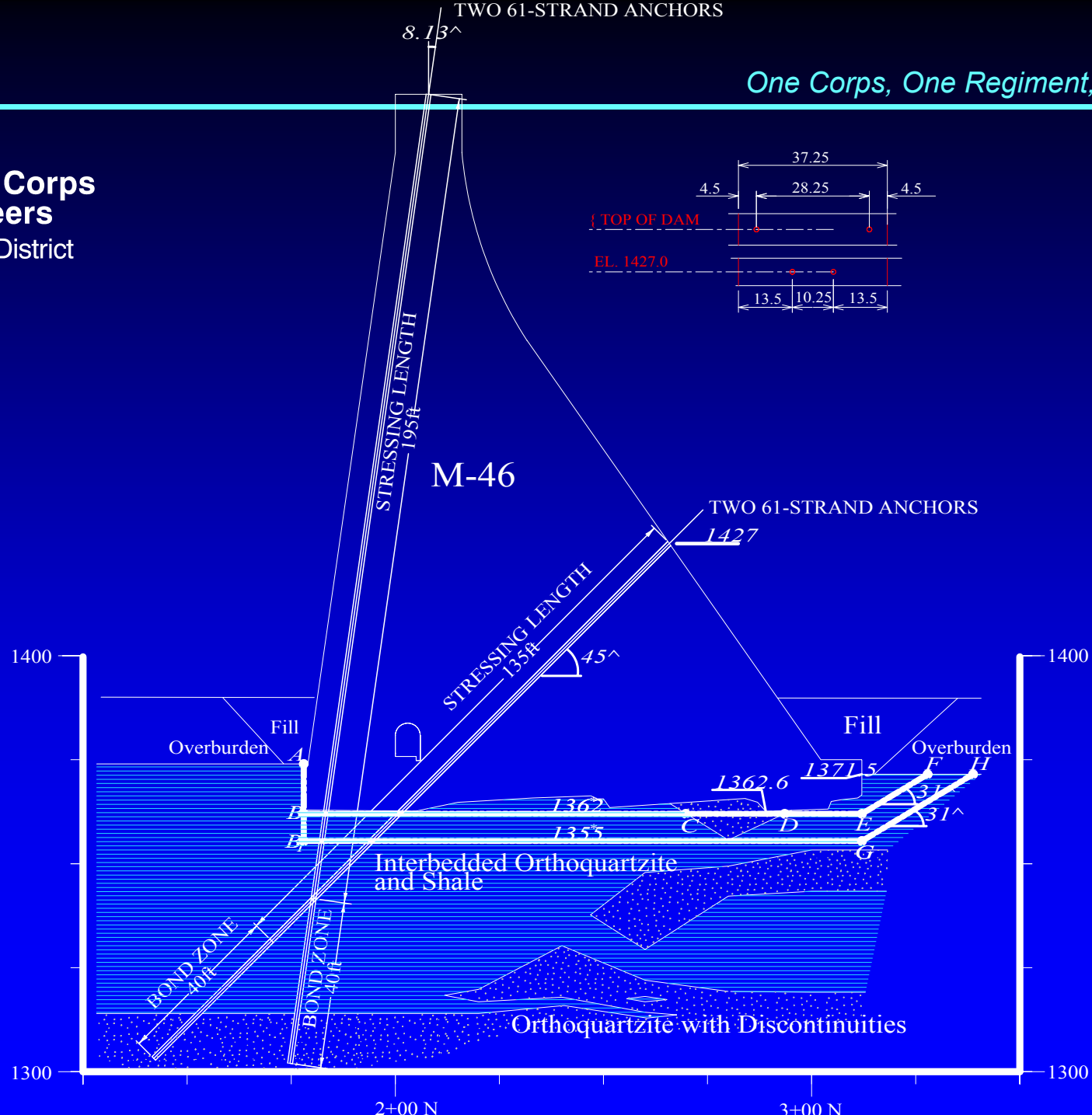
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		BLUESTONE DSA	MON 46	2-45deg and 2 vertical anchors	
Each anchor has 61 strands, 2 row, with anchors spaced 8.33 feet apart.					
.06 inch strand, with design load 35.2 kips		# of strands	Design load kips	Max test load kips	
	Per strand	1	35.2	46.9	
	Per anchor	61	2147.2	2860.9	
	Anchors per monolith	4	8588.8		
ANALYSIS FOR TENSION ANCHOR SYSTEMS : ANCHOR DEPTHS (EM 1110-1-2908)					
Description			Symbol	Value	
S = factor of safety			FS=	4	
c = rock mass cohesion intercept*			c=	9536.0	psf
F = anchor force required for stability			F=	2147200	pounds
γ = unit weight of rock			w=	102.6	pcf
s = anchor spacing			s=	9	ft
l = row spacing (for anchors with multiple rows)			l=	20	ft
Application			Formula		Results
single anchors in competent rock			$\sqrt{FS \cdot F / c \cdot 3.14159}$		16.9
single row of anchors in competent rock			$(FS \cdot F) / cs$		100.
multiple row of anchors in competent rock, with a factor of safety of 1.5			$(FS \cdot F) / wls$		174.398960
single anchor in fractured rock, with a factor of safety of 1.5			$\sqrt[3]{(3FS \cdot F) / (w \cdot 3.14159)}$		31.
single row of anchors in fractured rock, with a factor of safety of 1.5			$\sqrt{FS \cdot F / ws}$		59.
multiple row of anchors in fractured rock, with a factor of safety of 1.5			$(FS \cdot F) / wls$		174.398960
c= a weighted average of the cross bed shear strength					
single anchor in fractured rock with the compined force of all the anchors in that a			$\sqrt[3]{(3FS \cdot F) / (w \cdot 3.14159)}$		49.

BLUESTONE DSA		10-45deg	
Each anchor has 61 strands, 3 rows, with anchors spaced 9 feet apart, rows spaced 10 feet			
.06 inch strand, with design load 35.2 kips	# of strands	Design load kips	Max test load kips
Per strand	1	35.2	46.816
Per anchor	61	2147.2	2855.776
Anchors per monolith	10	21472	
ANALYSIS FOR TENSION ANCHOR SYSTEMS : ANCHOR DEPTHS (EM 1110-1-2908)			
Description	Symbol	Value	
S = factor of safety	FS=	4	
c = rock mass cohesion intercept*	c=	9536.0	psf
F = anchor force required for stability	F=	2147200	pounds
w = unit weight of rock	w=	102.6	pcf
s = anchor spacing	s=	9	ft
l = row spacing (for anchors with multiple rows)	l=	10	ft
Application	Formula	Results	
single anchors in competent rock	$\sqrt{FS \cdot F / c \cdot 3.14159}$	16.9	
single row of anchors in competent rock	$(FS \cdot F) / cs$	100.0	
multiple row of anchors in competent rock, with a factor of safety of 1.5	$(FS \cdot F) / wls$	348.797920	
single anchor in fractured rock, with a factor of safety of 1.5	$\sqrt[3]{(3FS \cdot F) / (w \cdot 3.14159)}$	31.0	
single row of anchors in fractured rock, with a factor of safety of 1.5	$\sqrt{FS \cdot F / ws}$	59.0	
multiple row of anchors in fractured rock, with a factor of safety of 1.5	$(FS \cdot F) / wls$	348.797920	
c = a weighted average of the cross bed shear strength			
single anchor in fractured rock with the compined force of all the anchors in that a	$\sqrt[3]{(3FS \cdot F) / (w \cdot 3.14159)}$	66.9	

CALCULATING BOND LENGTHS FOR ROCK ANCHOR SYSTEM

ROCK TYPES PRESENT	AVG. THICKNESS (ft.)	BOND STRENGTH (psi)	
Orthoquartzite with Discontinuities	12.00	200	(test)
Interbedded Orthoquartzite and Shale	28.00	130	(test)
Claystone (lower)	0.00	50	(test)
TOTAL THICKNESS OF BOND ZONE:	40 feet		
	WEIGHTED MEAN:	151	psi
		Working Bond Strength	

COMPARISONS - VARYING HOLE DIAMETERS:

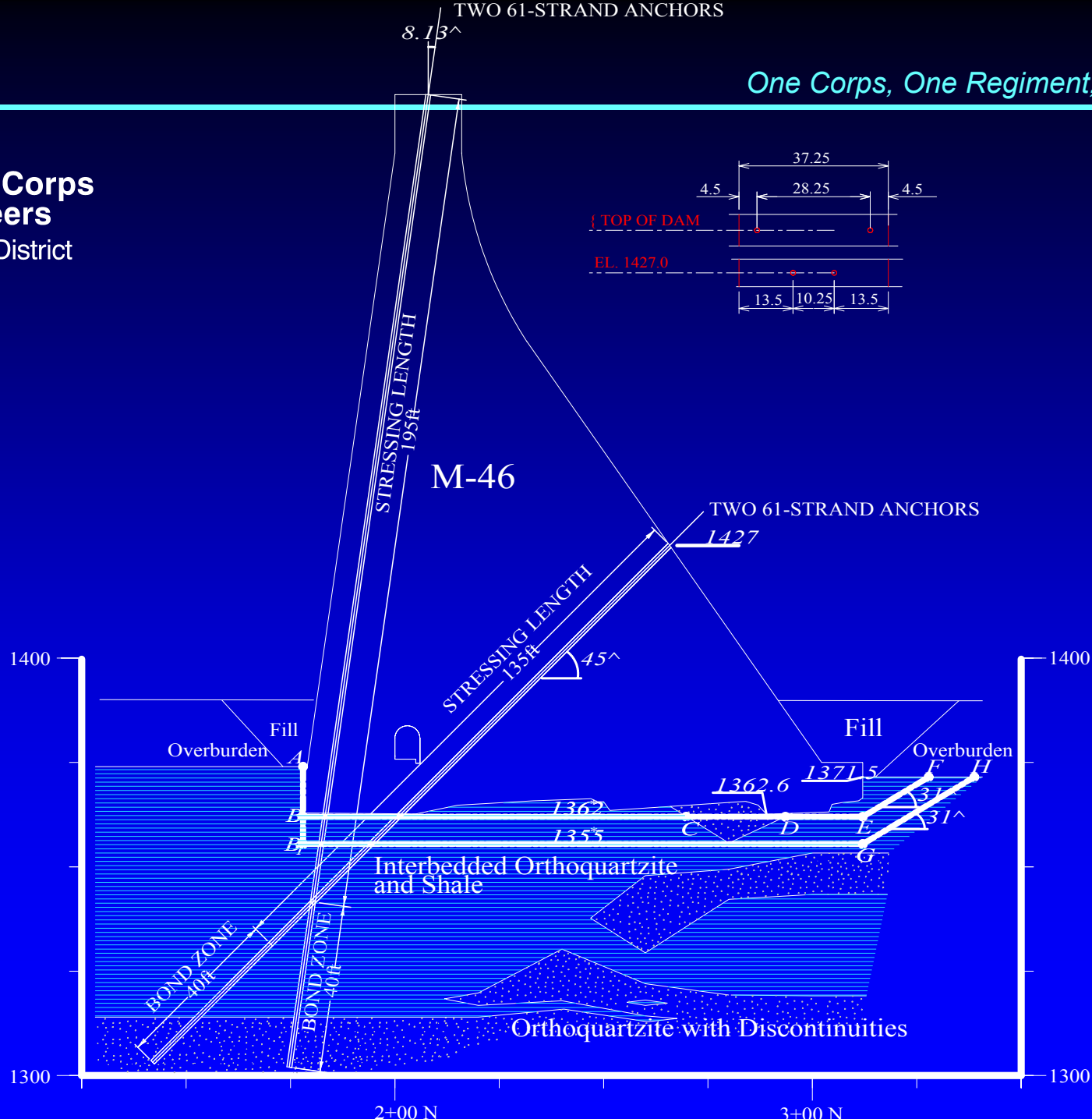
COMPOSITE LITHOLOGY using working bond strength, and various diameters

MAXIMUM KIPS:	2861	2861	2861	2861
ANCHOR BOND STRENGTH (CHOSEN):	151	151	151	151
HOLE DIAMETER (in.):	14.00	14.50	15.00	15.50
RADIUS	7.00	7.25	7.50	7.75
BOND AREA REQ'D. (sq. in.):	18946.36	18946.36	18946.36	18946.36
ANCHOR BOND LENGTH (in.):	431	416	402	389
ANCHOR BOND LENGTH (ft.):	35.9	34.7	33.5	32.4



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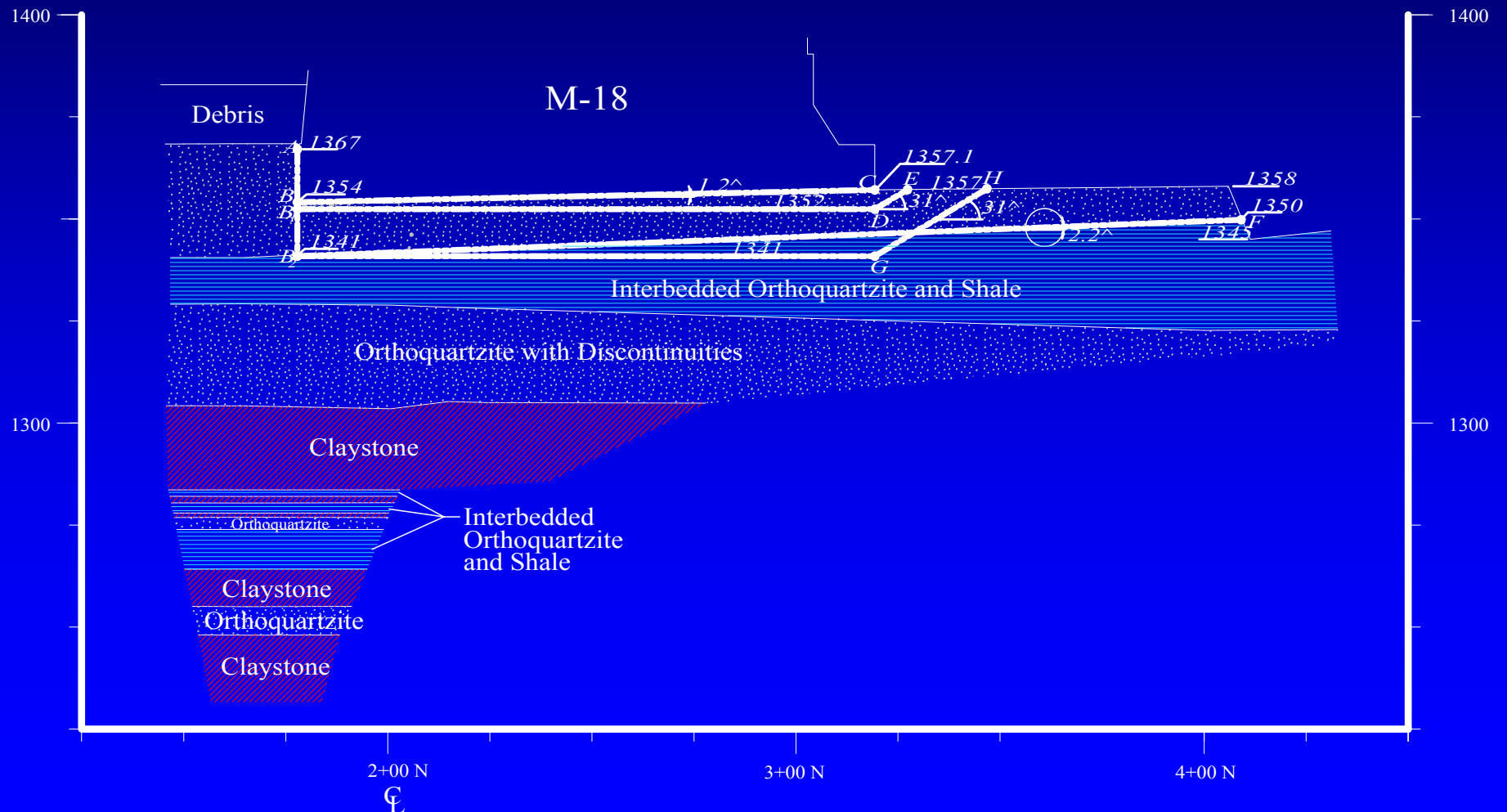
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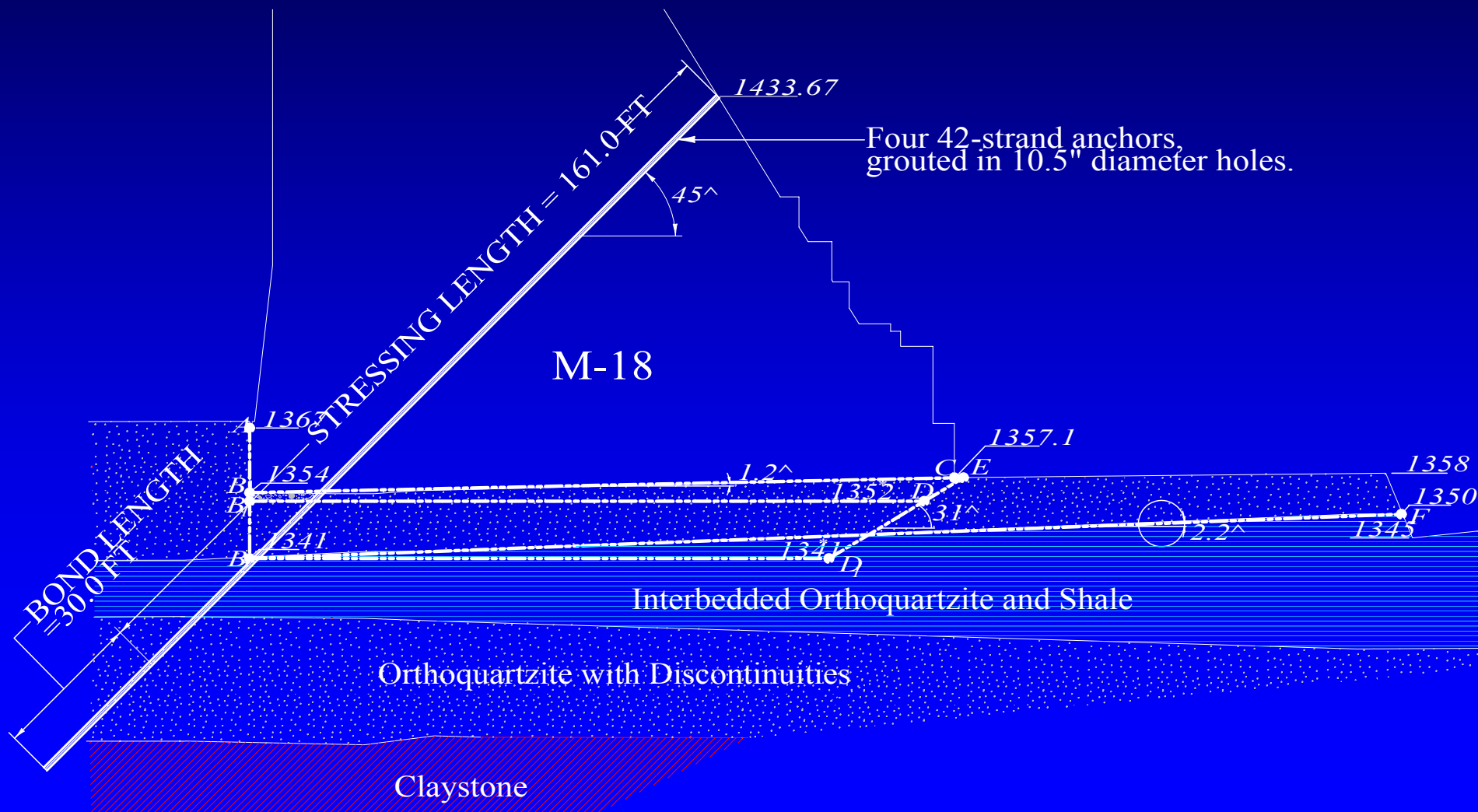
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Anchor Design





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Ongoing Studies

- ◆ **Full Scale Field Anchor Testing**
 - **Confirm Bond Strengths**
 - **Consolidation Grout Designs**
 - **Constructability & Production Rates**
 - ***Energy Transfer of Single grouting
VS Two Stage grouting**



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Field Study

- ◆ **Install Four 61 Strand Production Anchors**
 - Two from top of dam and instrumented (8°)
 - Two from face of dam (45°)
 - Corrosion protection is 10" corrugated polyethylene pipe
 - Bond zones forty feet.
 - Stressed lengths 150 to 180 feet.



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Field Study (cont.)

- ◆ **Install Eight Bond Stress Test Anchors**
 - 18 strand anchors in 5" holes.
 - Bond zones 10'.
 - Load to, or near, bond failure.
 - 4 lithologies tested.
 - Parallel lab pull-out tests for comparison



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Casagrande C12





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Drill Setup on Anchor BDA-46-2





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18" Down The Hole Hammer

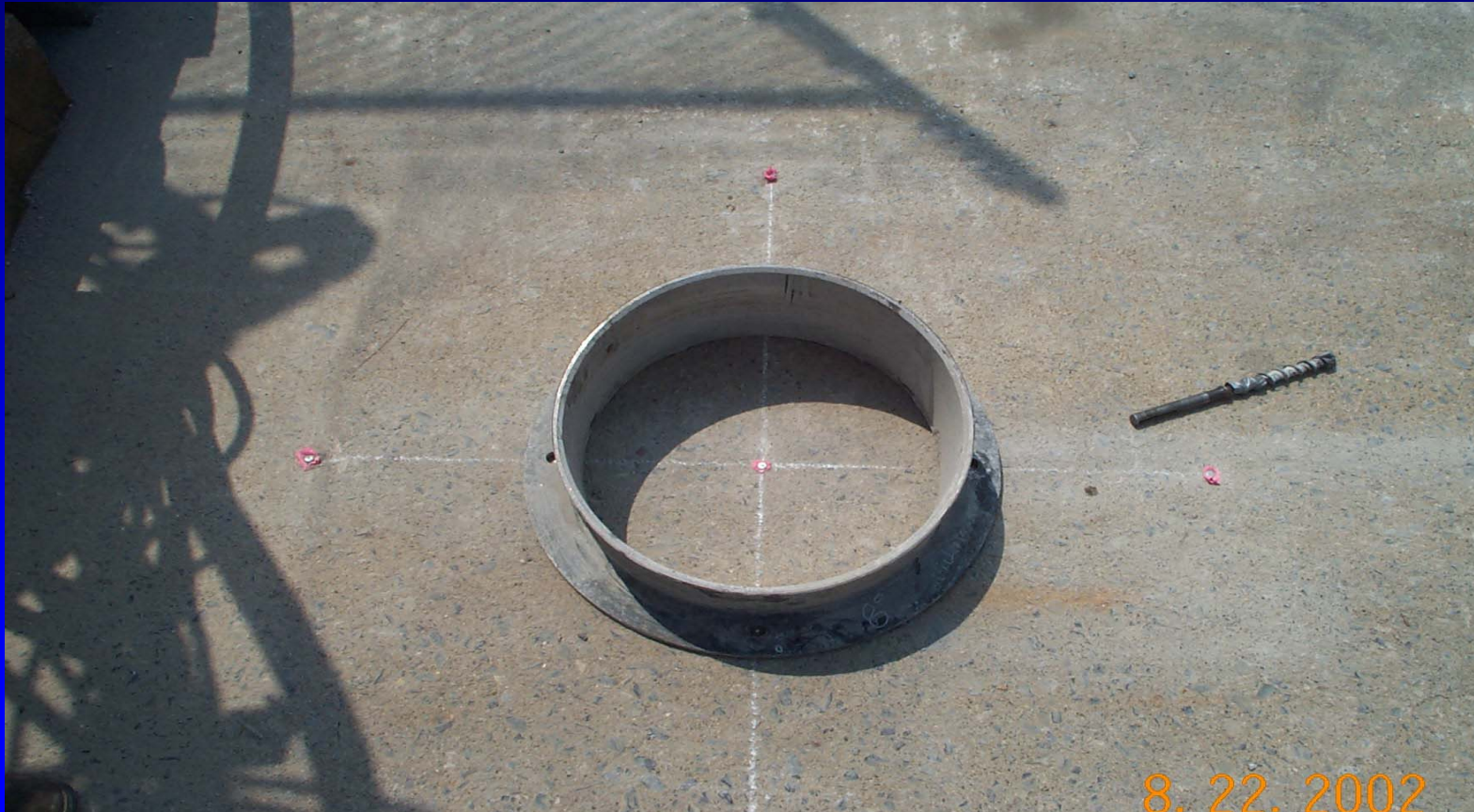




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Starter Guide





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18" Hammer Aligned in Starter Guide





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18" Hammer in Action





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18" Guide Boring Completed





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38" concentric Hammer





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38" concentric Hammer





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38" concentric Hammer





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38" Recess





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Sub-Bearing Plate and Trumpet



8.2



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Sub-Bearing Plate and Trumpet





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Bearing Plate





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Installation and Alignment





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Installation and Alignment





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Installation and Alignment



8.26.2002



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15" Hammer & Guide





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Corrugated





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Corrugated

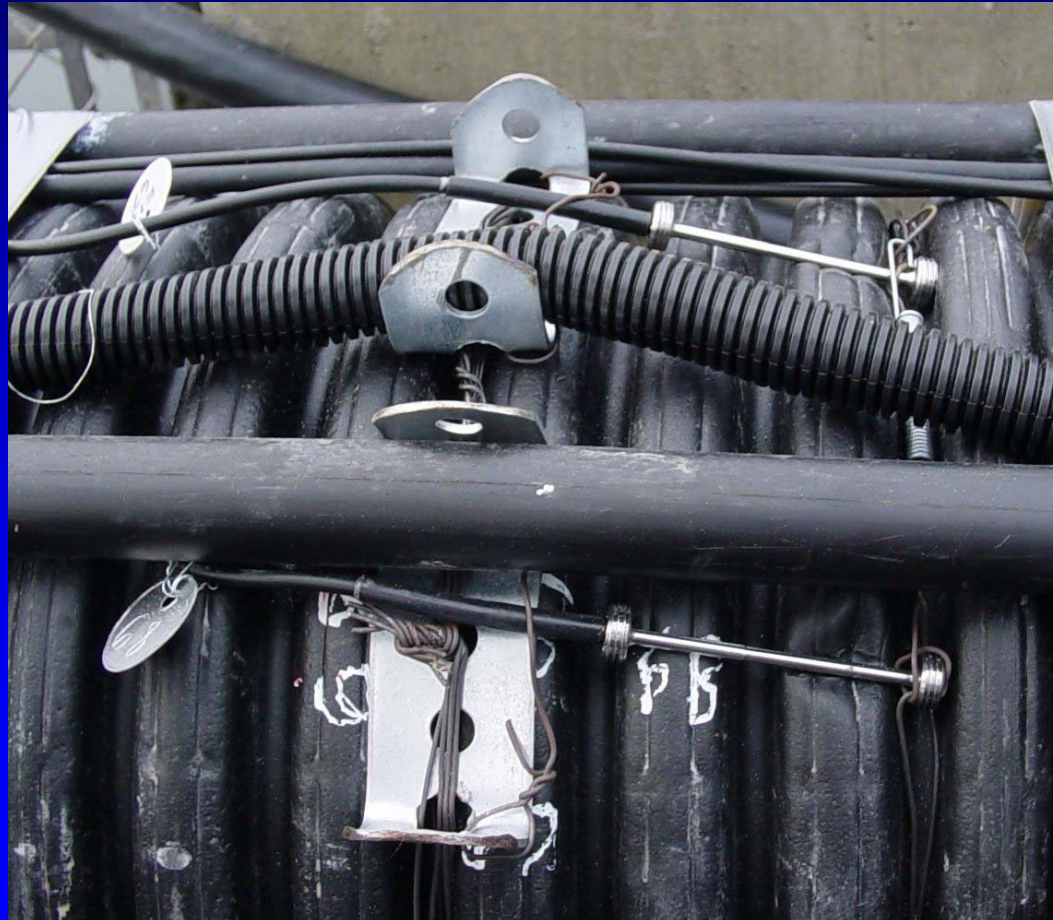




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Strain Gauges





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Strain Gauges





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61 Strand Anchor





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18 Strand Anchor





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18 Strand Anchor Installation





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18 Strand Anchor Installation





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18 Strand Anchor Installation





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18 Strand Anchor Installation





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18 Strand Anchor Installation





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Grouting 18 Strand





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Grouting 18 Strand





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Questions ?